INSTRUCTIONS

FOR

AERIAL PHOTOGRAPH SCALE-CHECKING

Issued by

Cartographic Section

East Central and Northeast Divisions

Agricultural Adjustment Administration

July 1937

PART I

OFFICE PROCEDURE

RECOMMENDATIONS FOR OFFICE PROCEDURE

AERIAL PHOTOGRAPH SCALE-CHECKING PROGRAM

INTRODUCTION

The purpose of scale-checking, or, more properly, scale determination, is to secure ratios for making photographic prints to any desired scale. In order to do this, the scale of the contact prints must be determined by finding the relation between the ground length and the photographic length of selected lines. Since a photograph has a different scale at each point of different elevation, the ground elevations of the lines must be found.

In order that the program may be executed with the greatest economy, it must be carefully planned so that the field work necessary to obtain these ground distances and elevations is reduced to a minimum This is accomplished by utilizing all available existing information and by judicious selection of the scale-check photos and lines.

The necessary photographic measurements are made on the contact prints. It is preferable that the contact prints be on a non-shrink base so that they will be the same size as the film from which the ratioed prints are made.

A photo-index on a scale of about one inch to a mile is essential in the planning and carrying out of the program.

The office work is divided into three parts; namely,

I. Planning the Program

II. Office Methods for Obtaining Ground Distances and Elevations

III. Scale-Check Computations

I. PLANNING THE PROGRAM

A. Study of Existing Information

The first step in setting up a scale-check program for a given area is the study of all types of available horizontal and vertical control which may be used to eliminate or reduce the field work involved in getting ground distances and elevations.

In most areas at least one of the following types of control data will be available:

1. Existing traverse nets (U.S.G.S., U.S.C. and G.S., etc.)
2. Railroad and highway plans (large scale)

The location of available information of this type should be shown by suitable symbols on the photo-indices.

Any existing maps of scale 1" = 2000' or larger, such as U.S.E.D. river surveys, planimetric maps, and, in some states, public land surveys, should be secured, as ground distances for scale-checking may be scaled directly from such maps.

All topographic maps and other data which give elevations of the terrain in the photographed area should be obtained. The

location of all known or identifiable bench marks and level lines should be shown on the photo-index.

B. Frequency of Scale Checks

A rapid check of the tilt and scale quality of the photos in an area, by close examination of the index and by making scale comparisons of adjoining photos, will indicate the necessary frequency of scale checks. Flights with photos of uniform scale and small tilt usually require scale-checks on about every eighth or tenth photograph, and flights having photos of widely varying scales and large tilts may require scale-checks on nearly every photograph. Methods for examining the photographs for these qualities are discussed in Appendix A.

In general, scale-check prints should be selected on an average of about 1 print in 5, with not more than 2 or 3 over-hanging photos left at the ends of the flight, and not less than 2 scale-checks in any flight. Flight "breaks," points where the flying is not continuous, must be treated the same as the ends of flights. All such breaks should be clearly marked on the index.

Another consideration in determining the frequency of scale-checks is the cost of obtaining them. When it is possible to get the necessary ground information in the office, or by an inexpensive field method such as automobile speedometer measurement, it may be advantageous to scale-check at frequent intervals, rather than transfer ratios over long distances between the scale-check photos.

When only alternate photos and/or alternate flights are to be enlarged, they should be chosen before the scale-checks are selected, so that the required number of scale-checks will be reduced to a minimum. In selecting the photos to be enlarged, badly tilted prints should be avoided so far as possible.

C. Selection of the Scale-Check Photographs

The selection of scale-check photographs is made on the photo-index. As each photo is selected it should be marked on the index as a guide to the location of the remaining scale-checks.

A transparent template showing the outline of a photo at the scale of the index should be made so that the boundaries of each photo being studied may be found. The contact print should be used for detailed study of the photo's suitability for scale-checking.

The selection of photos for scale-checking should be based on the following considerations:

1. The photo must have good image-points suited to the most advantageous placement of the scale-check lines as described in the following section.
2. Preference should be given to photos on which the cost of scale-checking can be reduced by the use of existing information.
3. Photos on which the scale-check points can be coordinated with their correct geodetic positions should be chosen whenever possible, because of the value of such points as control in any future mapping program.

4. Scale-check photos in overlapping flights should be adjacent, so that some of the scale-check lines will serve both flights.

5. When three adjoining flights have about the same scale and good side overlap, it may be possible to eliminate some scale-checks by transferring scales to the center flight from the other two.

6. Badly tilted photographs, which are to be enlarged, should be scale-checked so that the necessary information for making "restored" prints will be available if it is found desirable to use such data.

7. In selecting the scale-check photos that are to be sent to the field, it should be kept in mind that:

   a. The terrain between the terminals of a scale-check line, which is to be measured by the field party, should be as open as possible. In this way a minimum number of set-ups and a minimum amount of line-clearing will be necessary.

   b. The line should be located in an area which is readily accessible to the field party.

D. Selection of Scale-Check Lines

The image-points used as the terminals of scale-check lines must be sharp and definite. The type of points which are desirable as scale-check points is discussed at length in the

instructions for field work. The terminals of lines which are obtained in the office should be, as far as possible, the same type images.

Scale-check lines to be measured in the field should be selected in the office and indicated on the contact prints by circling the approximate positions of the line terminals with "china-marking" pencils. These circles should be 1/2" to 1" in diameter and should encircle several possible image points, leaving the selection and pricking of the actual image-point to the field men. Scale-check lines between non-coordinated images should be shown by drawing a straight line between the china-marking circles.

All scale-check lines requested from the field should be marked by suitable symbols on two photo-indices, one of which should accompany the scale-check photos to the field. China-marking pencils may be used to indicate requested lines and coordinated points.

Each scale-check photo should have from 1 to 3 scale-check lines, with a minimum length of 2 inches on the photo and 3000' on the ground. Of course, where the ground distances are to be obtained from existing traverse lines and the length of the line does not affect the cost, the lines should be made as long as possible.

Practically all photos have enough tilt to cause the scales and enlarging ratios to vary considerably across the print. The scale at the principal point (optical center) is very nearly

the average scale of the photograph and should be used in determining ratios.

Any scale-check line gives the scale of the photo at only one point which may be called the scale-point. The Scale-point lies on the scale-check line or an extension of it. The center point of the scale-check line is midway between the scale-point and the intersection of the scale-check line with a perpendicular dropped from the principal point (more strickly, from the iso-center).

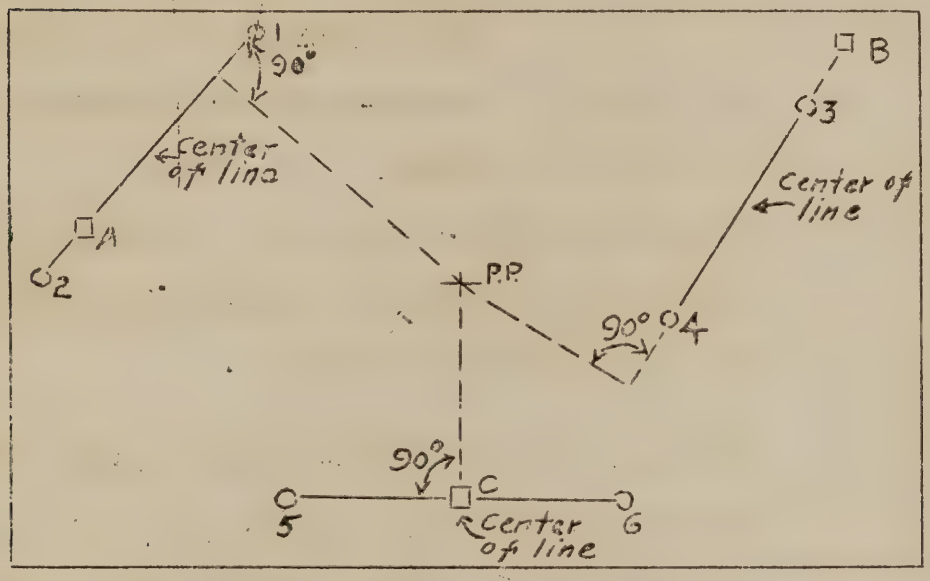

Figure 1

Figure 1 is a sketch of a typical scale-check photo, showing three scale-check lines, (lines 1-2, 3-4, 5-6), the principal point (P.P.), and the scale-points (A, B, and C) of the given lines.

Following this principle the scale-check lines should be placed according to the number of lines to the print as follows:

One line- The scale-point must be very close to the principal point.

Two lines- The lines should be so placed that a line connecting their scale-points passes through, or close to, the principal point, and their scale-points should be as widely separated as conveniently possible.

Three lines- The lines should be so placed that their scale-points form a triangle as large and as nearly equilateral as possible. Great care should be taken to keep the three scale-points from falling in a straight line.

Badly tilted photos should have a minimum of three lines so that it will be possible to compute the amount of the tilt by the method given in Appendix B.

The first and last scale-check and alternate intermediate scale-check photos in a flight should have three scale-check lines, or should have at least two strong lines so placed that a line connecting their scale-points passes close to the P.P. and is parallel to the line of flight. The remaining scale-checks may have only one line.

II. OFFICE METHODS FOR OBTAINING GROUND DISTANCES AND ELEVATIONS

It must be kept in mind that each of the several steps in the computing of ratios introduces small errors which may at times be additive. For

this reason every possible effort should be made to keep the error of each step to a minimum.

Ground distances measured by tape and transit methods, as described in the instructions for field work, should have an accuracy of 1:1000. Distances obtained in the office from railroad and highway plans, and other large scale maps will not be as accurate, but may be within the limits of requirements for the work.

In choosing between the various methods, the relative accuracy and cost of each method should be carefully weighed.

Since the procedure to be followed in the field is given in the instruction for field work, only the information which should be supplied to the field party by the office will be mentioned here.

The field party should be supplied with:

1. A photo-index and contact prints showing the approximate location of all requested scale-check lines. The names of the principal towns, streams, railroads, and highways should be on the index.
2. All available information concerning existing traverse lines and bench marks which they are to use, including their location on the indexes and other convenient maps, descriptions and sketches of the locations of the monuments and hubs.

All computations necessary to secure line-lengths and point coordinates from the field notes should be made in the office.

A. Office Operations for Obtaining Ground Distances

1. Ground distances may be obtained directly from large scale maps by scaling.

2. Many railroad and highway structures, such as switch points, bridge and trestle ends, large culverts, road crossings, etc., are identifiable on the photographs. The ground distances between such points may be found without recourse to field work by utilizing the curve notes and "plus differences" given on the plans.

Structures, shown on the plans, which cannot be positively identified on the photograph in the office should be identified in the field. The field party should be furnished with a sketch of that portion of the plans on which the point is located, a description of the point, and the approximate position of the point on the photo. The field party may find it advantageous to use the requested structure as a hub and tie in by spur traverse some nearby identifiable point.

Railroad plans usually show more identifiable structures than do highway plans, and they are generally more satisfactory.

B. Office Operations for Obtaining Ground Elevations

The need for ground elevations in getting photographic scales depends on the topography of the photographed area,* and the flying height of the plane. The change of photographic scale due to differences of ground elevation varies inversely with the flying height. For example, an elevation difference of 100' will cause a scale change of 1% if the flying height is 10,000', and only 1/2% if the flying height is 20,000'. For a given flying height, the scale varies directly as the elevation difference. To be somewhat comparable with the accuracy required for ground distances, ground elevations should be considered when the photographed area has elevation differences exceeding one half per cent of the flying height.

When the nature of the terrain makes it necessary to consider ground elevations, it is convenient to assume a common datum elevation for the photographed area, ratio all photos to give the desired scale at this datum elevation, and then change the ratio of each separate photo to the average elevation of that photo. Obviously, it may sometimes be desirable to make two or more prints of each photo, ratioing each print to the elevation of some part of the photo.

---

*Note: If every photo to be ratioed is to be scale-checked (as is sometimes done in relatively flat sectionalized areas suited to the use of automobile scale-checks), the relative elevation of various points on each photo is the determining factor.

Elevations of all scale-check line terminals must be obtained so that the elevation at which the scale of the line applies will be known. These elevations may be taken from existing topographic maps and railroad or highway profiles. When no such maps are available, barometric leveling, as described in the field instructions, should be used. The location of existing bench marks and level stations which may be used as a base in running barometric levels should be furnished to the field parties on a photo index and other convenient maps.

The average elevations of intervening photos between scale-checks may be most easily obtained from topographic sheets (such as USGS contoured Quadrangle sheets).

When such maps are not available, the average elevation may be found from a stereoscopic study of the photos. In making this study, without the instruments for measuring parallax, it will be necessary to have frequent spot elevations. A preliminary stereoscopic study of the area should be made to determine the location of these spot elevations.

The elevations of scale-check line terminals will furnish some of the necessary elevations. Points where additional spot elevations will be needed should be marked on the index and contact prints and requested from the field along with the other scale-check information.

III. SCALE-CHECK COMPUTATIONS

A. Preparation of Photos

The field parties will furnish the following data on scale-checks made by them:

1. On the face of the photo, the images of scale-check line terminals will be pricked and circled.
2. On the back of the photo the approximate position of the lines will be shown, and the descriptions and elevations of the line terminals will be given.
3. The data necessary for the determination of ground distances will be given in field notes accompanying the photograph.

As soon as the scale-check photos are returned to the office from the field, each scale-check point should be examined to see whether or not the image pricked agrees with the description given for it. No image improperly marked or described should be used for ratio determination.

Photos scale-checked in the office should show the same information as those scale-checked in the field.

For ratio computation purposes, positions of the image points should be accurately transferred to the backs of the prints, in the office, by holding the photo against a light source and placing the tip of a pencil behind the pricked image. A pencil dot should be made at that position; never prick through an image, as enlarging the pricked hole destroys the value of a sharp image.

All transfers of lines from one photo to another should be made in the office. To aid in this transfer and to preserve a record of the scale-check data obtained, the exact position of the lines should be marked in ink on the photo index. The following symbols may be used for this index:

Coordinated point- Ink circle 0.2" diameter with point number in the same color ink. It will be convenient to designate such points by the number of the photo on which the point was secured.

Non-coordinated line- Ink circle 0.1" diameter at each terminal. Connect terminals with the same color ink line and write number of photo on which the scale-check originally appears along this line.

Lines obtained in the office should also be shown on the office index, but they should be distinguished from those obtained in the field by the use of contrasting colors.

B. Nomenclature

In the discussion of scale-check computation procedure the following nomenclature will be used:

L = Ground length of scale-check line (feet)

P = Photographic length of scale-check line (inches)

S = Scale (feet per inch)

S_p = Photographic scale

S_d = Datum scale

S_t = Desired scale

Y_1 = Elevation of high terminal of line

Y_2 = Elevation of low terminal of line

Y_e = Equivalent elevation of the line*

Y_a = Average elevation of photo

f = Focal length of camera lens (inches)

H = Flying height = f x S

x = Distance in inches between the high terminal of the line and the foot of the perpendicular to the line from the principal point.

R_d = Ratio of enlargement or reduction for datum elevation

R_a = Ratio of enlargement or reduction for elevation Y_a

The distance "p" should be measured between the pricked points by using a scale graduated in hundredths of an inch and estimating the reading to the nearest thousandth of an inch with the aid of a lens. To avoid parallax the scale should be held at an angle of about 60° with the photo and the reading made by sighting the pricked image along the graduation markers. The pricked points should be illuminated by placing the photo on a light table.

Construction lines for obtaining x should be drawn on the back of the photo and x measured, with just sufficient accuracy to make the computed value of Y_e correct to the nearest five or ten feet.

*Note: The equivalent elevation of a scale-check line which has unequal terminal elevations is the elevation at which a level line in the same horizontal ground position would have to be placed so that the photographic lengths of the two lines would be the same on any given photograph. In other words, the equivalent elevation is the elevation at which the photographic scale prevails.

C. Ratios for Scale-Check Photos

Formulas:

1. $S_p = \frac{L}{P}$

2. $Y_c = Y_2 + \frac{x}{P}(Y_1 - Y_2)$*

   x is negative when the high terminal of the line lies between the low terminal and the foot of the perpendicular from the principal point, and is positive for all other positions.

3. $S_d = S_p + \frac{(Y_c - Y_d)}{f}$

4. $R_d = \frac{S_d}{S_t}$

After R_d has been computed for each line, the scale-points should be located on the back of the photo and joined by straight lines. The ratios (R_d) apply at the scale-points.

If the field work and computations are correct, any differences between these ratios is due to tilt.** Since the ratio changes caused by tilt vary as a straight line in any direction, the ratio at any point on the photo may be found by straight line interpolation.

---

*Note: See Appendix B for limitations of this formula.

**Note: When any line on the photo gives a ratio differing greatly from those given by other lines on the photos, the photo should be carefully checked for tilt by the scale comparison method. If this test does not show evidence of tilt sufficient to cause the ratio differences shown by the scale-check lines, the ground distances and elevations should be re-checked. It should be kept in mind that field work is expensive, and no photo should be sent back to the field for checking until every possible means of locating the error in the office has been exhausted.

Example:

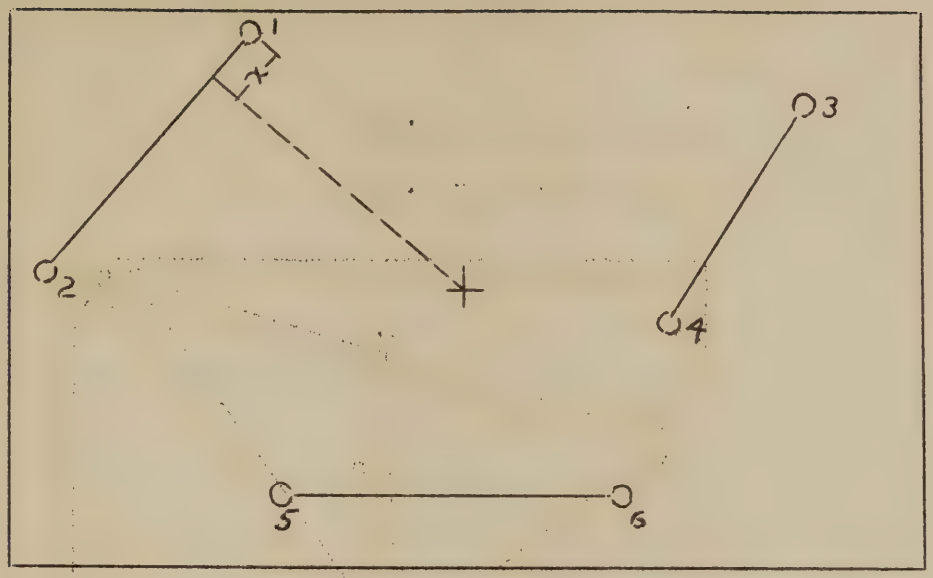

Figure 2

Line 1-2 (Fig. 2)

L = 5,000'

P = 3.704"

Y_1 = 600'

Y_2 = 500'

x = +0.6"

f = 8.000"

S_t = 1320' per inch

Y_d = 600'

$$S_p = \frac{5000}{3.704} = 1350 \qquad (1)$$

$$Y_e = 500 + \frac{+0.6}{3.7}(600 - 500) = 515' \qquad (2)$$

$$S_d = 1350 + \frac{515 - 600}{8} = 1339 \qquad (3)$$

$$R_d = \frac{1339}{1320} = 1.014 \qquad (4)$$

This ratio applies at the scale point A.

The ratios for lines 3-4 and 5-6 are found in the same manner and apply at B and C, respectively. These ratios were found to be

Line (3-4), $R_d = 1.000$

Line (5-6), $R_d = 1.003$

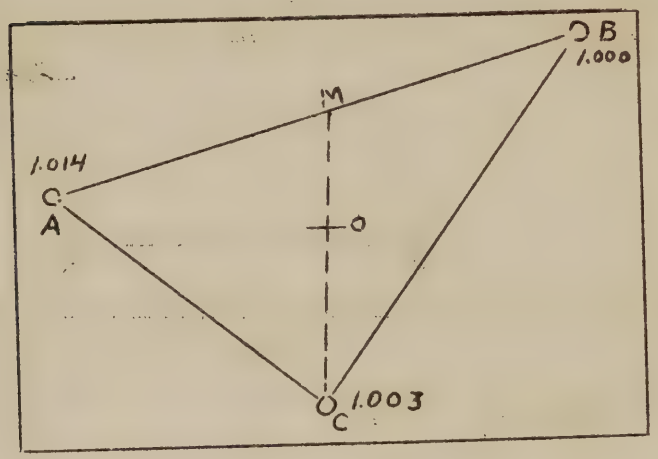

Figure 3

Figure 3 shows the scale points A, B, and C, which were previously shown in Figure 1, connected by straight lines to form a triangle.

The point "M" is found by the intersection of the dashed line drawn through B and the principal point (O) with the line AC.

Line AB = 8.25"

MB = 3.52"

MC = 4.9"

OC = 2.8"

Using these values $R_{(O)}$ (the ratio of the principal point) may be found by straight line interpolation as follows:

$$R_{(M)} = 1.000 + \frac{(1.014 - 1.000)}{8.25} \quad (3.52) = 1.006$$

$$R_{(O)} = 1.003 + \frac{1.006 - 1.003}{4.9} \quad (2.8) = 1.005$$

D. Ratios on Intervening Photos Between Scale-Checks

If the preliminary check of the relative scales of the photographs has indicated that a uniform flying height has been maintained throughout a flight, datum ratios for intervening prints between scale-check photos may be interpolated on a straight line basis.

When the flying height is not uniform, the ratio transfer should be made by a "scale comparison traverse" from photo to photo.

The lines chosen for this comparison are the same as described in the test for tip (in Appendix A), perpendicular to the air base and lying near the principal points of adjoining photos. The ratios of these lines at the scale points (which should lie on the connecting air base) are found from the ratio variation on the photo by interpolation (or by extrapolation, if necessary). This computation can only be made on photos having three scale-check lines or at least two lines whose scale points lie in the line of flight.* The ratio between the lengths of the lines on the scale-check photo and the photo next in line, multiplied by the ratio of the lines on the first photo, gives the ratio of the lines on the second photo. These ratios are

---

*Note: When it is not possible to find the true ratios for the scale comparison lines on the initial photo of the traverse, both ratios may be assumed to be the same as the principal point ratio. If this assumption is wrong, the traverse will not close and must be adjusted.

then projected to the next pair of scale comparison lines, and carried forward until the next scale-check is reached. This ratio traverse should, of course, check into the scale-check data of the next scale-check, and should it not, the traverse must be adjusted. The adjustment is made on a straight line basis, giving equal weights to each ratio in the traverse.

Example:

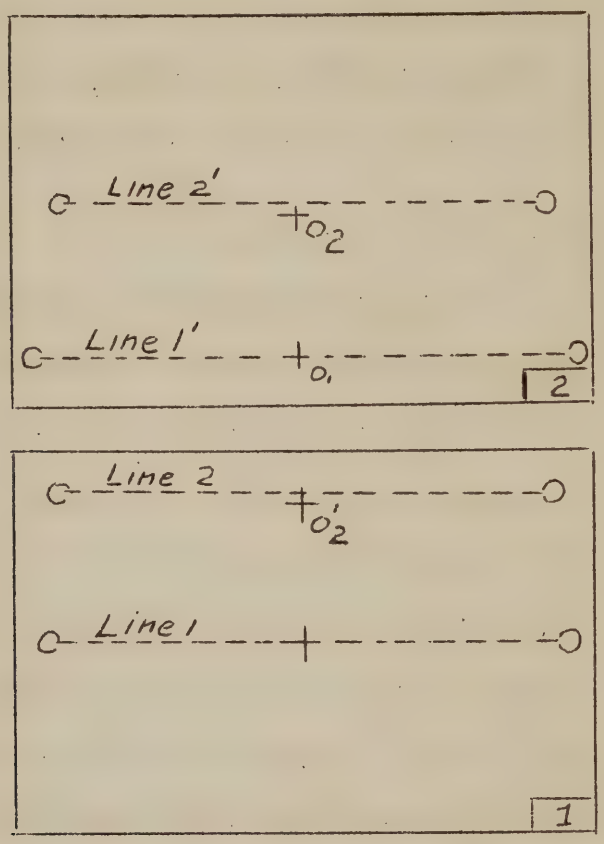

Figure 4

Figure 4 shows a pair of overlapping photos with the scale comparison lines 1, 1', 2, and 2'.

Photo 1 Line 1 = 8.068, R_1 = 1.005

2 = 7.580 R_2 = 1.007

Photo 2 Line 1' = 8.050

2' = 7.565

$$R_1' = \frac{8.068 \times 1.005}{8.050} = 1.007$$

$$R_2' = \frac{7.580 \times 1.007}{7.565} = 1.009$$

The following table shows the results of a scale comparison traverse and the adjusted ratios.

Photo Number	Scale-Check Ratio	Transferred Ratios	Correction	Final Ratios
1	1.005			1.005
2		1.009	∕1	1.010
3		1.008	∕2	1.010
4		1.012	∕3	1.015
5		1.010	∕4	1.014
6	1.015	1.010	∕5	1.015

In practice it will usually be sufficiently accurate to estimate these changes from photo to photo by flip matching of images. Since, in this method, it is desirable to work with ratios near unity, the mean scale of the contact prints should be used for S_t in obtaining datum ratios.

E. Ratios for Average Elevation of Photo

After datum ratios (R_d) have been obtained for all photos, ground ratios (R_a), necessary to make a ratioed print of the desired scale at the average elevation of the photo, should be found.

$$R_a = R_d \div \frac{Y_d - Y_a}{H_t}$$

where $H_t = fS_t$ is a constant for given values of f and S_t.

Example:

$R_d = 1.010$

$Y_d = 600'$

$Y_a = 800'$

$H_t = 8.000 \times 1320 = 10560'$

$$R_a = 1.010 \div \frac{600 - 800}{10560} = 0.991$$

In practice $\frac{Y_d - Y_a}{H}$ may be found mentally with a sufficient accuracy.

F. Nib-Distances for Making Ratioed Prints

The distance between the camera collimation markers (commonly called "nibs") is called the contact nib-distance, and is constant for all photos made with a given camera. The ratioed nib-distance, which is equal to the contact nib-distance multiplied by the ratio R_a, is the distance that the nibs will be apart on the ratioed print.

Example:

$R_a = 0.991$

Contact nib-distance = 8.920

Ratioed nib-distance = $8.920 \times 0.991 = 8.840$

Ratioed nib-distances provide a convenient means for making ratioed prints and should be sent to the photographer in the place of ratios.

If a non-shrink paper, such as Positype, is used for the contact prints, a constant contact nib-distance measured on the film may be used; but if the contact prints are made on paper which may differ in size from the film, the contact nib-distance should be measured on each photograph.

G. Recording the Results of Computations

Plates 1 and 2 show the forms necessary to record the results of the computations. The last column on Plate 2 is used to record the actual nib-distance on the enlarged prints.

APPENDIX A

Examination of Photos for Tilt and Scale Quality

In the following discussion the component of tilt about an axis parallel to the line of flight will be called list, and the component about an axis perpendicular to the line of flight will be called tip.

When a photograph has list, the area photographed is moved in a direction perpendicular to the line of flight, causing the photo to be set out of the flight strip. Because of this offset or "throw," these photos can be easily picked out by examination of the photo index, unless the offset is obscured by "crab."

Assuming that the plane flew in a straight line for three consecutive exposures, the throw, (N), of the principal point of the center photo from a straight line connecting the first and third photo centers, divided by the focal length (f) of the camera lens equals the tangent of the angle of list (θ_L). That is, Tan $\theta_L = \frac{N}{f}$.

The throw due to tip has the effect of apparently lengthening or shortening the air base between successive photos. Air-base lengths are usually so variable that this test for tip is seldom of much value.

Any large variation in scale between adjoining photos will be revealed by the scale comparison method described below.

In the scale comparison method, images on adjoining photos are superimposed by "flickering" one photo above the other and examination is made for image displacements or scale changes. In the test for list, two adjoining photos are matched along their common air-base. With the photos

in this position, any relative displacement of images perpendicular to the air-base indicates that the two photos are tilted with respect to each other. The amount of this displacement (E) varies approximately as the degree of tilt, the square of the distance (A) of the image from the air-base, and inversely as the focal length (f) of the lens. An idea of the magnitude of this displacement is given in the following example:

When $\theta = 3^{\circ}$, f = 9.43", and A = 3"

E = +0.04" on the "raised" side of the photo

E = -0.06" on the "depressed" side of the photo

Tip is checked by comparison of scale differences along two lines taken perpendicular to the air-base and passing near the respective principal points of the two photos. If the two exposures were made at different flying heights, the scales on the two photos will be different; but if the photos are level, the scale differences between respective lines on the two photos will be the same. When this condition does not hold, relative tip is indicated.

The amount of this tip may be judged by following the principles laid down in Appendix C for finding tilt from ratio variation.
By assuming (as is usually true) that most of the photos in a flight strip are nearly level, it is possible, with the use of these tests, to pick out those photos which are badly tilted.

APPENDIX B

Limitation of Y_c Formula

When the elevation difference of the line terminals is greater than;

$$Y_1 - Y_2 = 0.0447 \frac{PH}{Q}$$

where Q is the perpendicular distance from the principal point to the scale-check line, a correction must be applied to the value:

$$Y_c = Y_2 + \frac{K}{5}(Y_1 - Y_2)$$

Correction to be Applied to Y_c

To obtain the corrected value (Y_{cc}) of the equivalent elevation, apply the correction:

$$K = -\frac{K}{2H} \frac{Q(Y_1 - Y_2)^2}{P}$$

(Note that the correctional value K is always negative.)

Then:

$$Y_{cc} = Y_c + K$$

APPENDIX C

Tilt Determination by Ratio Variation

The determination of the amount of tilt in a photo is a simple computation when the ratios at various scale-points are known. Three scale-point ratios are needed to determine the amount and direction of the total tilt, but two scale-point ratios are sufficient to determine the tilt component about an axis perpendicular to the line joining them; the ratios of the scale comparison lines used in transferring ratios from photo to photo are sufficient to determine the tip of the photos.

The angle of tilt (θ) is given by the formula

$$\tan \theta = f R$$

where R is the rate change of ratio.

The axis of total tilt is a line of constant scale and is parallel to all lines of constant scale on the photo. Any line drawn through two points of equal scale is a line of constant scale.

The direction of maximum scale change is obviously at right angles to the direction of no scale change.

It is convenient to work with ratios rather than scales.

Example:

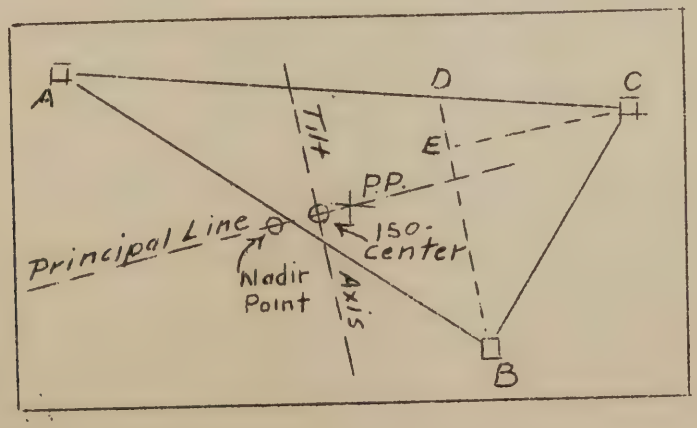

Figure 1

Figure I shows three scale-points (A, B, and C) joined by straight lines to form a ratio-triangle. The ratios R_A, R_B, and R_C are 0.990, 1.000, and 1.005, respectively.

Point D was found by interpolation between A and C, so that

$$R_D = R_B = 1.000$$

Line BD, then, is a line of constant scale and is parallel to the tilt axis.

Line EC is drawn perpendicular to line BD and is parallel to the direction of maximum ratio change R

$$\tan \theta = f \quad R = f \frac{R_C - R_E}{EC} = 10. \frac{1.005 - 1.000}{3.25} = 0.015$$

$$\theta = 0^\circ - 50'$$

The nadir point and iso-center lie on the principal line, which is the line through the principal point perpendicular to the tilt axis. Their respective distances from the principal point are:

Principal point to nadir point = $f \tan \theta$

Principal point to iso-center = $f \tan \frac{\theta}{2}$

Their direction from the principal point is toward the smaller ratios; that is, in the direction in which R is minus.

Theoretically, the perpendiculars used in determining equivalent elevations and scale-point positions should be dropped from the nadir point and the iso-center respectively.

To obtain a closer value of the tilt angle, a second tilt determination should be made using equivalent elevations and scale-point positions which have been corrected by dropping the perpendiculars as described above.

PART II

FIELD ENGINEERING PROCEDURE

CONTENTS
OF
INSTRUCTIONS FOR SCALE-CHECKING AERIAL PHOTOGRAPHS
(FIELD WORK)

ILLUSTRATIONS

INSTRUCTIONS FOR SCALE-CHECKING AERIAL PHOTOGRAPHS

1. Definition and Purpose.

The term "scale-checking," as used in this instruction, may be more properly described as "scale-determination." In other words, the purpose of this work is not to check the scales of photographs, but rather to determine the scales of photographs. Another purpose, no less important, is to identify ground control points (points for which plane coordinates have been determined) for use in controlling maps which may be compiled from the photographs. As much as possible, the field work will be planned so that these two purposes are both satisfied with one field operation.

The scale determination is necessary for computing "ratios" for making ratioed prints, reductions or enlargements to any desired scale. The use of plane coordinates of points is for scale-checking as well as possible future use as control for the laying of aerial photograph mosaic maps or other planimetric maps.

2. Materials and Information Supplied to Field Party.

(1) Index map of photographs on which the office has indicated by suitable symbol, in crayon, the following:

(a) The approximate location of each point to be coordinated, by a red crayon circle.

(b) The photographs on which distance scale-checks only, are desired, will be indicated by red crayon circles connected by a red crayon line at the approximate position at which the scale-check is desired.

(c) The approximate locations of all traverse control lines bench-marks, highways upon which plans are available, and railroads for which right-of-ways maps are available, distinguishing between the different types of traverse by suitable symbol.

(2) List of descriptions, coordinates, survey notes and elevations on all available traverse and level points, and prints of highways and railroads within the area to be worked.

(3) The necessary instrumental equipment includes a light transit, steel tapes*, finely-pointed plotting needles, magnifying glass for plotting

* It is believed by the writer that the increased speed and accuracy, which could be obtained by using 500' tapes, will more than off-set the cost of purchasing 500' tapes, and it is recommended that each field party be furnished with 3/16" 500' tape, and tape grips.

work, and duplicating field notebooks.*

3. Selecting the Scale-Check Points.

This is perhaps the most important step in the entire program. The field men must always strive for a sharp, fine, clearly defined point which can be plotted on any of the adjoining photographs from description alone. The following are typical of what may be considered good points:

(1) Intersection of fences, when not obscured by shadows. (Note: Well defined hedgerow almost as good as fence.)

(2) Corners of buildings, when not obscured by shadows, always specifying by directions which corner was used, and noting also whether the point used was at the roof or at the ground. (Try to avoid using corners of high buildings. Be sure to plot the corner of the building or the roof, and not its shadow.)

(3) Sharply defined intersection of trails, or intersection of trails and fences.

(4) Isolated small trees or bushes, (In using a tree, be sure to plot the center of tree itself, and not its shadow.

(5) Well defined structures along a good road or railroad, such as end of bridge, large culvert, etc.

(6) Transmission line towers. (Be sure to spot the base and not the inclined image.)

Points which are formed by the intersection of lines will, in general, be more likely to show on all photographs than those points which show as a dot. Intersections of lines should make an angle of at least 45°, however. Thus, fences, roads, etc., that intersect at angles of less than 45° should be used with caution. The points to be used should always be first selected on the photograph, and then identified on the ground.

Where several scale-check points are available, strive to select the best point. It is poor practice to try to save a few hundred feet of traverse or taping by selecting one of the less desirable points. Typical poor points which should not be used so long as better points

* Duplicating field notebooks similar to K. & E. F361D should be used exclusively.

can be found are:

(1) Large intersection of roads, expecially where angle of intersection is less than 60 degrees.

(2) Cultivation lines, these being unreliable because of the danger of change, also because cultivation lines tend to fade out on enlargements.

(3) Large trees, tree rows, or woods lines, because these features are usually not definite or sharp enough.

(4) Drainage lines, such as creek intersections or sink holes, not definite enough.

(5) Grass tips, because they tend to "feather out."

(6) Any point which, while clear on one photograph, may on adjoining photographs be hidden by trees, buildings, or shadows.

4. Pricking the Points.

Always use a finely pointed plotting needle, working under magnifying glass. If plotting hand is unsteady, try steadying by resting on straight edge, or by using the other hand as steadying hand. Try to get the needle hole to pierce just through the emulsified surface of the double-weight paper, but not pricking completely through the total thickness of paper. The criterion for proper depth of needle prick is that, when the photograph is placed on a light table, the light will shine through. A few experiments will convince anyone that it is possible to prick needle holes which will allow light to shine through without the necessity of punching all the way through the double-weight paper. The pricking must be done while the needle is exactly vertical. A slanting, or non-vertical, needle is likely to let the light come through in such a way as to cause incorrect scaling. The pricked point must, of course, be exactly on the proper image, within visual limits. A person with good eyes, working under magnifying glass, with steady hands, should be able to prick a point in proper position on the photograph within .002 inch. The diameter of the needle prick should be between .001 and .003 inch. A good needle prick will have a diameter equal to the width of a fine black graduation line on a scale divided into 100 parts per inch.

Each point should be pricked on one photograph only. The transfer of all such points to adjoining photographs will be done as an office operation. As soon as the point is selected and pricked, a small circle about 1/4 inch in diameter should be drawn around the point on the face of the photograph,

using red "Scripto" pencil. The photograph should then be reversed, held up to the light, and a similar red circle drawn on the back of the photograph.

The point-pricking operation is, perhaps, the most painstaking operation of the field work, requiring a high degree of skill, and must be precisely and meticulously executed. It is true that some field men, because of defective eyesight or unsteady hands, will be unable to do this sort of plotting within the specified limit of error. Such persons should not be assigned to this operation. If the chief of party is not able to do this work properly, one of the other men on the party should be assigned as field plotter.

5. Descriptions of Points.

Each scale-check point must be concisely but completely described. Each description will appear in two places, first, on the back of the photograph, secondly, in the field notes. The description in the field notes may sometimes be made more complete than the description on the photograph. The description on the back of photograph must be legibly lettered or written near the scale-check point.

In general, the more brief these descriptions are, the better, but no important item should be omitted. General descriptions, such as required for a bench mark or traverse monument, are not required. The red crayon circle on the face of the photograph will give the approximate location, sufficient to replace the usual general description. The type of description desired is local only, and should be just complete enough so that the exact point can be identified on any of the adjoining photographs, or on the ground, from its description alone.

It is recognized that such an ideal description will not be possible in all cases. Nevertheless, the field man should be constantly striving to select points which can be so described, then to write the proper descriptions for them. The following examples indicate the type of descriptions desired:

(1) "X intersection of fences." ("SW corner of garden fence," a very common description.)

(2) "T intersection of fences."

(3) "SE corner of barn at roof line."

(4) "Intersection of fence and center-line of lane."

(5) "Lone cedar tree in pasture."

(6) "Isolated bush, central one of group of five."

6. Field Surveys for Coordinated Points.

Within or near each area circled in crayon on the index map, the field man will select a point, plot it, and make the necessary measurements so that its coordinates can be computed. It may happen that a traverse point itself is identifiable on the photograph, and can be plotted directly. This will seldom be the case, however. More often it will be found that the traverse point is not directly identifiable, and that the field man has to select some point which can be identified and plotted, then make the necessary angle and distance measurements.

If the desired points are located near existing traverse stations, an azimuth and distance tie from the nearest traverse station will suffice. Quite often more than one course will be required. Such ties are known as spur ties, because they are not carried through and tied to another traverse station. Their measurements, therefore, must be carefully checked to eliminate mistakes. Accordingly, in all spur lines, the taped distances must be checked either by stadia readings which are correct within 1% or be double-taped. On long courses, this accuracy and stadia check will require intermediate set-ups, and it is recommended that stadia be not read over 1000 feet. The accuracy of all measurements must be of 1:1000, or better, and for lines of 1 mile or greater (of which there will be very few) closed traverse should be used. Angles should be measured by transit to the nearest minute, reading the A vernier only. These angles must be read on the azimuth circle and shall be doubled to guard against mistakes in reading the vernier. A compass needle bearing shall be recorded for each course. In addition to control lines of various governmental agencies, highway and railroad control will be available in a considerable portion of the area covered by pictures. It is obvious that the coordinated control should be used in all cases where it is available since most scale-checks can thereby be had with less work, and a further advantage will accrue of furnishing control for future maps at no extra cost.

It is true that the railroad and highway surveys will not be coordinated to the State Projection System. However, these lines are to be used as control traverse whereever available, and assumed coordinates will either be used or the traverse will be used as a broken line scale-check whichever the State Office deems most advisable.

7. Field Surveys for Distance Scale-Checks (Not Coordinated).

It will be necessary, a great number of times, to determine scales of photographs where coordinated control points are not available. These are termed distance scale-checks. The procedure is simply to tape distances on the ground between selected points, called distance points or scale-check terminals. Such points must be selected, described, and precisely plotted, in exactly the same manner as specified for coordinated points. The general location and number of these lines will be selected by the State Office and shown on the photographs as red circled areas connected by red lines, and the points to be used as terminals must be selected within the red circle.

Wherever possible to do so without increasing the amount of field work to any appreciable extent, it is desired that the distances be taped in a straight line between the terminals so that computations may be reduced, keeping in mind, however, that it is much cheaper to do office work than field work.

If straight, clear courses for direct taping between the scale-check terminals cannot be found, the so-called 'broken base' method should be used. This is simply a random traverse between the two scale-check terminals, using the same methods of making measurements as outlined for the 1:1000 photo control traverse. Each broken base is later reduced to a straight line distance by latitude and departure computations. Also, compass-needle bearing should be read and recorded. See specimen notes, Figure 3.

The same accuracy is required in the taping of distance scale-check lines, namely 1:1000. The taping must be checked, by stadia measurements correct to within 1%, or by double-taping, whichever is most convenient. The form of notes to be used for distance scale-check lines is illustrated in Figure 4.

(A) Automobile Distance-Measuring*

(1) Calibration of Speedometer. The 10th wheel of the speedometer is to be taken off and carefully graduated to 1/100th of a mile. A fine wire is to be soldered across the center of the speedometer face, and is to be used as a cross hair in reading mileage. The tires are to carry, at all times, 35 pounds of air and are to be driven at a constant speed of 15 miles per hour while scaling pictures. Cars are to be checked against measured miles on surface and gravel roads in order to obtain constant correction for speedometer readings, i. e., against measured mile on hard surface roads the speedometer reads 0.987,

*These are tentative instructions to be revised after study of results of experimental automobile scale-checking tests now being made in Kentucky.

then the mileage should be multiplied by 1.013 for all distances measured on hard surface roads. If the mileage were to read 1.076 for a measured mile on gravel roads, then the mileage should be multiplied by 0.929 to obtain the correct mileage for scale-checks measured on gravel or dirt roads. Distances are to be measured by automobile on dry roads only.

(2) Instructions for Measuring. The points must be selected, described, and precisely plotted in exactly the same manner as specified for other scale-checks or coordinated points. Select and flag the points before the scale-checking is done. Pass the scale-check point and read the speedometer as the point is passed. Drive to the second point and read the speedometer as the second point is passed while the car is moving. For a check, turn around and run the scale-check in the opposite direction. Never start and stop on the point nor should the speedometer be set at zero, but rather the speedometer should be read on the 2 points and the difference between the two readings is the scale-check distance, unadjusted. These two distances should check to within 1%. Speedometer readings are to be made to 1/1000th of a mile, and no distances are to be less than 2 miles. See figure 5 for traverse notes.

8. Elevations on Scale-Check Points.

In order that the scale of each photograph may be determined so that the picture is correct for scale at a specified datum, or, in other words, to calculate for relief displacement of photograph images, it is necessary to determine an approximate elevation on each scale-check point. Such elevations should be shown to the nearest 10 feet. Elevations may be determined by one of several methods. Whenever topographic map sheets of the U. S. G. S. are available, elevations should be interpolated therefrom. Wherever elevations may be obtained from bench marks, highways, or railroads, vertical angles measured with a transit, using scale distances from the photographs or distance readings on the stadia board, may be used. Be sure to determine elevation for the precise point selected and plotted. For example, if a building corner is at roof line, determine the elevation for the roof line, and not for the ground. If the plotted point is the top of a smoke stack, determine the elevation for the top of the stack, and not the ground.

Where other means of determining elevations are not available, it will be necessary to use aneroid barometers. These aneroid barometers will have to be adjusted by the U. S. Bureau of Standards at Washington, D. C., before being used by the field party. In a number of the counties there appears to be few bench marks. The party chief will first study the index sheets showing the bench marks, and the scale-check locations and

proceed to establish barometric bench marks along the roads in such places as to be of the most use in determining the elevations of the photographic points. Set barometric bench marks at about 3 miles intervals along the principal roads and check back to known bench marks and adjust out the error. In no cases shall the time interval, between taking off and tying-in to known bench marks, be greater than 2 hours. After the photographed area has been fairly well covered with barometric bench marks, the scale-checks are commenced. Take off from the barometric bench marks and read elevations on the scale-check points, check back to barometric bench marks at no greater than 2-hour intervals, and adjust errors where the difference is greater than 15 feet, keeping in mind that the period of greatest change in atmospheric pressure is between 9:30 A. M. and 2:00 P. M. It might be well to obtain barometric elevations from 3:30 P. M. to the close of day in order to obtain more nearly correct elevations. In reading barometric elevations, the barometer should be laid flat in the shade for 5 minutes and tapped gently with the finger 2 or 3 times before reading.

In some counties there may not be any bench marks. In this case a line of fly levels may be run diagonally across the county. The ordinary method of running fly levels should be used, attempting to balance the fore and rear shots, sights as great as 1000 feet being permitted. An effort should be made to run these levels with an error of not greater than 0.2 of a foot per mile. However, in case greater errors are encountered, the field men should not re-run the level lines until the office so orders, since even a 10-foot error across a county when adjusted out is not serious to control the picture vertically.

A great number of the counties will not have a sufficient number of the elevations to obtain the datum on those prints between the scale-checked photographs. In those cases, the State Office should require additional elevations. These will be obtained by the party chief along the principal roads at 1-mile intervals and spotted on the index print with red crayon.

9. How to Designate the Points.

Coordinated or scale-check points shall be designated by the number of the photograph followed by a capital letter as A, B, C, etc., using a new set of letters for each photograph. The full designation of a point would then be the photograph number followed by the point letter as: 79-A, 79-B, 79-C, etc.

In showing the letter of a point on either the back or face of the photograph show only the point-letter since the photograph number already appears on the photograph. On the field notes, however, it will be necessary to show the full designation including the photograph number.

Traverse stations or stations on a broken base shall be designated by

numbers, as 1, 2, 3, 4, etc.

10. Field Notes.

Four sets of specimen field notes are shown on Figures 1, 2, 3, and 4.

Figure 1 illustrates two cases of spur ties to scale-check points, the first being a one-course tie, the second a two-course tie.

Figure 2 illustrates notes for a spur tie from railroad or highway traverse.

Figure 3 illustrates notes for a typical case of distance scale-checks, where the two lines originate at a common point, but neither can be directly measured.

Figure 4 illustrates notes for direct taping of distance scale-checks.

The method of determining the elevation of each scale-check point should be noted in the elevation column directly under the elevation figure, for example B. L. indicates barometric leveling, U. S. G. S. indicates elevations interpolated from contours of U. S. G. S. topographic maps, V. A. indicates vertical angles from some point of known elevation.

The field notes should be arranged in such a way that, as much as possible, each photograph will have its own independent set of notes. For example, do not try to show the notes for two photographs on one note page. The original sheets of the duplicating notes for each photograph shall be stapled to the photograph along its edge. Duplicating note books, properly numbered and labeled, will be assigned to each county office, or survey party.

11. Notes on Back of Photograph.

Information to be shown on back of photograph shall include the following:

(1) At lower right corner, show name of party chief, date of field work, and book and page number of duplicating field notes.

(2) Each scale-check point should be circled in red, circle to be from 1/8 to 1/4 inch in diameter.

(3) Near each scale-check point should be written:

(a) The point letter.

(b) The point description.

(c) The approximate elevation.

12. Inspection of Work by District Supervisors

Besides giving the field parties proper coaching and instructions, each District Supervisor must actually inspect some of the work of each party chief, by taking scale-checked pictures back to the field. While in the field, the descriptions of the scale-check points should be reviewed for completeness and conciseness; the judgment of the party chief in selecting the proper points should be considered; and the field notes should be reviewed for neatness and completeness. The accuracy of the measurements and elevations also should be tested and inspected, by actual occasional remeasurements and new determinations of elevations.

Such field inspection must be thorough and complete, and should cover approximately 25 per cent of the pictures handled by each field party at the beginning of the work. After a certain amount of inspection, it will be satisfactory to reduce the amount of checking on the work of those parties found to be doing good work, but to increase the amount of inspection of those parties which show up weak.

13. Checking Notes and Computing.

Upon completion of the field work, the party chief will check the field notes for their clearness and neatness. He shall pay particular attention to see that the proper identification of coordinated points is made so that the office will have no trouble in identifying the stations used. No computations will be done by the party chief in the field, but these will be handled in their entirety by the State Office.

14. Records and Transmittals.

After the scale-checks on any flight are completed, the original field notes are to be torn out of the note book and attached to the photograph to which they apply, and sent to the State Office along with a letter of transmittal, which lists every picture transmitted. Carbon copies are to be retained by the party chief for his records. The index map is to be sent in to the office after completion of the scale-check job, and is to be kept in good condition so that it might be used as a permanent record of work done. It shall not be folded, cracked, or the surface marred in any way. When taken to the field, it is to be fastened by Scotch tape to wall board and must always be kept flat.

FRANKLIN COUNTY, N.C.

4-6-37
Fair & Warm

Murphy
Long
Smith

Scale Checks - Photo 79-Flight G

Sta.	A-Ver.	Taped Dist.	Stadia	Needle	Elev.	
℄ on	N.C.E.R.A. Sta.		533+79	B.S. Sta.	518+12	N.C.E.R.A. Trav. Madison, N.C. to Winston, N.C.
	0°-00'	582.9	580	N10°W		
	350°-00'					
Sta 1	340°-00'					
	10°-00'L					
℄	on Sta 1		B.S. Sta.	533+79		
	0°-00'	1253.0	600	North	865	
	10°-00'		650		B.L.	
Point	20°-00'		1250			Point 79-A - S. Cor. Garden Fence
79-A	10°-00'R					200' ± S.E. Large Square House
℄	on Sta.	612+18	B.S. Sta.	582+79		N.C.E.R.A. Trav. Madison, N.C. to Winston, N.C.
	0°-00'	131.0	130	SIGE	825	
	10°-00'					
Point	28°-00'					Point 79-B - N. Cor of Garden Fence
79-B	10°-00'R					at "T" Road Intersection

FIG. 1-SPECIMEN NOTES ILLUSTRATING ONE COURSE TIE AND TWO COURSE TIE TO SCALE CHECK POINTS.

FRANKLIN COUNTY, N.C.

4-6-37
Fair & Warm

Murphy
Long
Smith

Scale Checks Photo 79 - Flight G

Sta.	A. Ver.	Taped Dist.	Stadia	Needle	Elev.
π on Sta. 418+50		21 B.S. Sta. 418+00			
	0°-00'	582.9	580	N10°W	
Sta	350°-00'				
1	340°-00'				
	10°-00' L				
π on Sta. 1		B.S. 418+50	21 (S'ld. RR.)		
	0°-00'	346.3	345		
	10°-00'				
Point	20°-00'				
79-A	10°-00 R				
π on 612+18		BS. 582+79			
	0°-00'	187.2	189		
	10°-00'				
Point	20°-00'				
79-B	10°-00 R				

Seaboard R.R.

Point 79-A - S. Cor. Garden Fence 200' ± S.E. Large Square House

N.C. Hwy. on U.S. #64 Madison, N.C. to Winston, N.C.

Point 79-B - N. Cor. of Garden Fence at "T" Road Intersection.

FIG. 2-SPECIMEN NOTES ILLUSTRATING SCALE CHECK TIES FROM HIGHWAY AND RAILROAD TRAVERSE.

FRANKLIN COUNTY N.C. — 5-6-36 Fair & warm — Murphy, Long, Smith

Scale Checks - Photo 76 - Flight G

Sta.	A. Ver	Taped Dist.	Stadia	Needle	Elev	
	π on Sta 1					
BS Point 76-A	0°-00'	583.0	585	S70W	885 B.L.	Point 76-A is N.W. Cor. of garden fence
	348°-00'					
	336°-00'					
FS Sta 2	12°-00' L	600.0	600	S58W		
	π on Sta 2					
BS Sta 1	0°-00'					
	14°-30'		700			
	29°-00'	1402	706	S73W	915 B.L.	
FS Point 76-B	14°-30' R		1406			Point 76-B is S. Cor. of garden fence 200' ± S.E. of large square house
	π on Sta 76-B					
BS Sta-2	0°-00'	2940	900			
	10°-00'		1000			
	20°-00'		540			
FS Point 76-C	10°-00' R		494			
			2934	S83W	945 B.L.	Point 76-C is N. Cor. of garden fence at "T" Rd. Int.

FIG. 3-SPECIMEN NOTES ILLUSTRATING METHOD OF INDIRECT MEASUREMENTS BY BROKEN BASES FOR DISTANCE SCALE CHECKS.

FRANKLIN COUNTY, N.C. 6-20-36 Storms
Fair & Warm Woods

Scale Check - Photo 76 Flight G

Sta	A.Ver	Toped Dist.	Stadia	Needle	Elev	
Point 76-A					990 B.L.	Point 76-A - is point of grass at N.E. Cor. of "T" Rd. intersection
		2955	800			
			780			
			750			
Point - 76-B			630		995 B.L.	Point 76-B is S.E. Cor. of large barn
			2960			
Point - 76-C					985 B.L.	Point 76-C is intersection of fences of "T" Rd South
		3539	650			
			445			
Point - 76-D			300		990 B.L.	Point 76-D is int. of ℄ of path and field Rd.
			900			
			800			
			440			
			3535			

FIG. 4-SPECIMEN NOTES ILLUSTRATING METHOD OF DIRECT TAPING FOR DISTANCE SCALE CHECKS.

FRANKLIN COUNTY, N.C.

Scale Sta.	Checks - Photo-76 Speed.	Mileage	Flight G Const.	Comput Dist.	Elev.	5-6-36 Fair + Warm	Murphy Long Smith
Point 76-A	12.012					Point 76-A is int. of fences at "T"	
		2.004	.997	10,549		Rd. South	
Point 76-B	14.016					Point 76-B is int. of grass line	
						and Rd. at Drive	
Point 76-B	15.281						
		2.003	.997	10,544			
Point 76-A	17.284			10,546	Mean		

FIG. 5-SPECIMEN NOTES ILLUSTRATING METHOD OF AUTOMOBILE TRAVERSE FOR SCALE CHECKS.

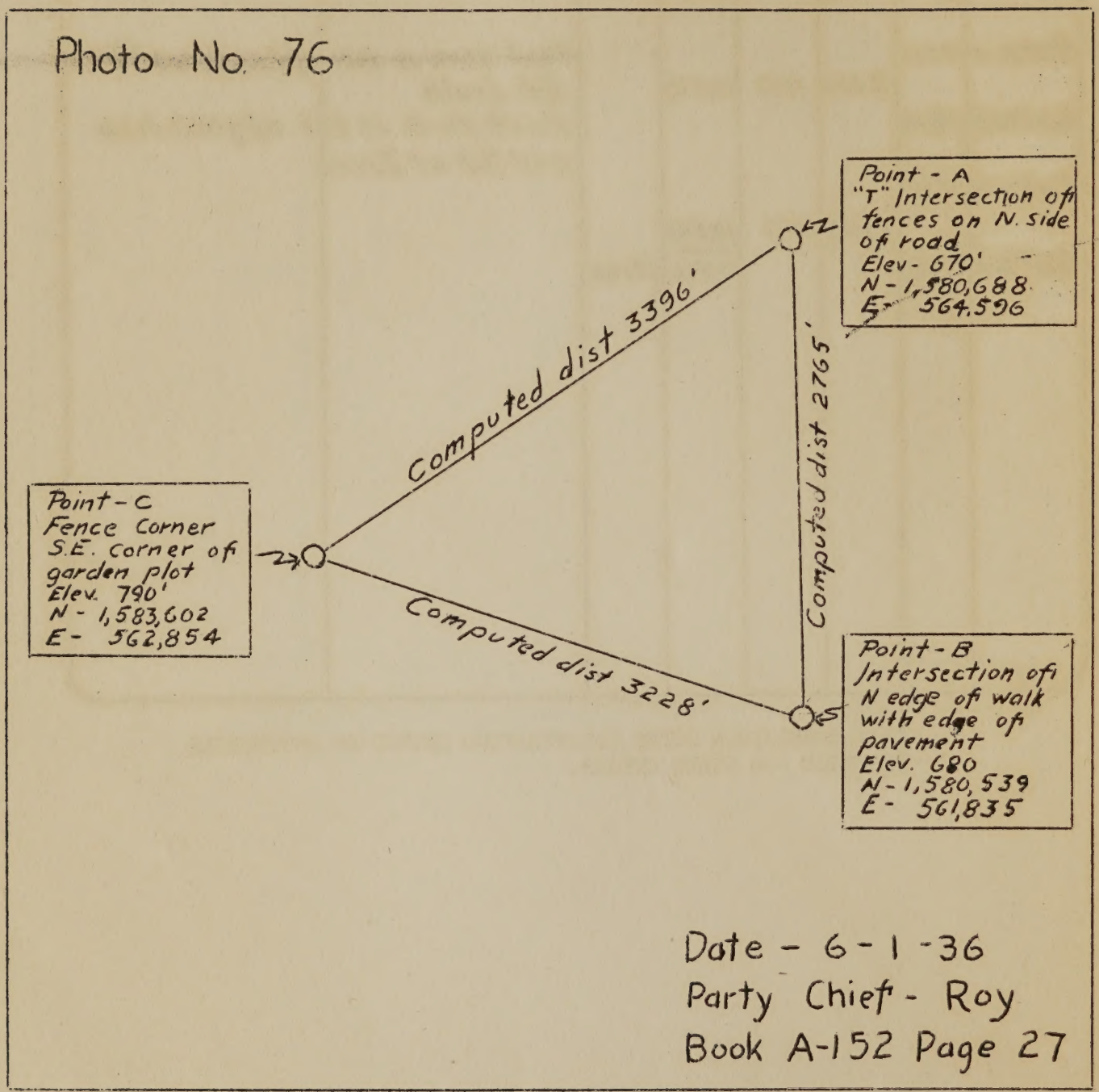

FIG. 6-BACK OF A TYPICAL SCALE CHECKED PHOTOGRAPH.
Note: Coordinates and computed distances to be filled in by State office.